J11A.1 **WEATHER RESEARCH AND FORECASTING MODEL SENSITIVITY COMPARISONS FOR WARM SEASON CONVECTIVE INITIATION**

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1. INTRODUCTION

Mesoscale weather conditions can significantly affect the space launch and landing operations at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). During the summer months, land-sea interactions that occur across KSC and CCAFS lead to the formation of a sea breeze, which can then spawn deep convection. These convective processes often last 60 minutes or less and pose a significant challenge to the forecasters at the National Weather Service (NWS) Spaceflight Meteorology Group (SMG). The main challenge is that a "GO" forecast for thunderstorms and precipitation at the Shuttle Landing Facility is required at the 90 minute deorbit decision for End Of Mission (EOM) and at the 30 minute Return To Launch Site (RTLS) decision. Convective initiation, timing, and mode also present a forecast challenge for the NWS in Melbourne, FL (MLB). The NWS MLB issues such tactical forecast information as Terminal Aerodrome Forecasts (TAFs), Spot Forecasts for fire weather and hazardous materials incident support, and severe/hazardous weather Watches, Warnings, and Advisories. Lastly, these forecasting challenges can also affect the 45th Weather Squadron (45 WS), which provides comprehensive weather forecasts for shuttle launch, as well as ground operations, at KSC and CCAFS. The need for accurate mesoscale model forecasts to aid in their decision making is crucial.

This study specifically addresses the skill of different model configurations in forecasting warm season convective initiation. Numerous factors influence the development of convection over the Florida peninsula. These factors include sea breezes, river and lake breezes, the prevailing low-level flow, and convergent flow due to convex coastlines that enhance the sea breeze (Laird et al. 1995; Lericos et al. 2002; McPherson 1970; Pielke 1974). The interaction of these processes produces the warm season convective patterns seen over the Florida peninsula (Manobianco and Nutter 1998). However, warm season convection remains one of the most poorly forecast meteorological parameters (Jankov et al. 2005). To determine which configuration options are best to address this specific forecast concern, the Weather Research and Forecasting (WRF) model, which has two dynamical cores – the Advanced Research WRF (ARW) and the Non-hydrostatic Mesoscale Model (NMM) was employed. In addition to the two dynamical cores, there are also two options for a "hot-start" initialization of the WRF model – the Local Analysis and Prediction System (LAPS; McGinley 1995) and the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS; Brewster 1996). Both LAPS and ADAS are 3-dimensional weather analysis systems that integrate multiple meteorological data sources into one consistent analysis over the user's domain of interest. This allows mesoscale models to benefit from the addition of high-resolution data sources. Having a series of initialization options and WRF cores, as well as many options within each core, provides SMG and MLB with considerable flexibility as well as challenges. It is the goal of this study to assess the different configurations available and to determine which configuration will best predict warm season convective initiation.

2. DATA/METHODOLOGY

This study employed the WRF Environmental Modeling System (EMS) software, which incorporates both WRF dynamical cores into a single end-to-end forecasting model. Three different combinations of WRF initializations were run, ADAS-ARW, LAPS-ARW, and LAPS-NMM, at a 4-km grid spacing over the Florida peninsula and adjacent coastal waters. A hot-start initialization of the NMM model using ADAS could not be run as the WRF EMS software does not support this configuration presently. Five convective initiation days were chosen over the June through September 2006 season. Candidate days were chosen based on the timing of the onset of convection and amount of convection over the peninsula during the forecast period. WRF simulations that had numerous active convective cells in the initial conditions were not considered for evaluation as the goal of this study was to assess model skill in forecasting convective initiation. Two null cases (non-convection days) were also chosen for this study. Each model run was integrated 12 hours with three runs per day, at 0900, 1200, and 1500 UTC. In addition, a comparison of the performance of LAPS-ARW using a high-resolution local

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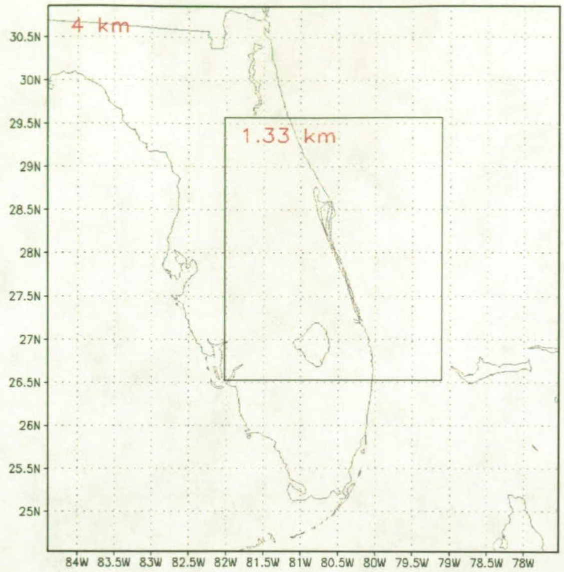


Figure 1. 4-km and 1.33-km WRF forecast domains.

grid with 2-way nesting, 1-way nesting, and no nesting was made for select convective initiation cases. The nested grid covered the east-central Florida region and was run at a resolution of 1.33 km. Figure 1 shows both the 4 km and 1.33 km domains.

The physics options used for the WRF runs included Lin et al. microphysics, Mellor-Yamada-Janjic planetary boundary layer scheme, Noah Land Surface Model for the land surface option, Janjic Eta surface layer scheme, Goddard shortwave radiation scheme (ARW), RRTM longwave radiation scheme (ARW), and the GFDL short and longwave radiation schemes (NMM). Boundary conditions were obtained from National Centers for Environmental Prediction (NCEP) North American Mesoscale (NAM) model on a 40-km domain, while initial conditions were obtained from the NCEP Rapid Update Cycle (RUC) model on a 40-km domain. Data ingested by the model through either the LAPS or ADAS analysis packages supplying the initial conditions included Level II Weather Surveillance Radar-1988 Doppler (WSR-88D) data from all Florida radars, GOES-12 VIS and IR satellite imagery, and surface observations throughout Florida (Case 1999).

To verify precipitation, the NCEP stage-IV analysis was used (Fulton et al. 1998). This analysis combines radar and rain gauge reports to produce hourly rainfall accumulation on a 4-km grid. Fractions Skill Score (FSS) (Roberts 2005), an objective precipitation verification method, was used to compare the model output to the stage-IV analyses. Fractions Skill Score is a variation on the Brier Skill Score and it answers the question of what spatial scales the forecast resembles the observations. The method involves computing a fraction for each grid square based on the number of surrounding grid squares in which there was precipitation. This gives a fraction, or a probability of precipitation, for each grid square based on the assumption that the model is in error on the scale of the size of the area used to produce the fractions. Once the fractions are obtained, FSS is computed as:

$$FSS = 1 - \frac{FBS}{\frac{1}{N}\left[\sum_{j=1}^{N}(p_j)^2 + (o_j)^2\right]},$$

where

$$FBS = \frac{1}{N}\sum_{j=1}^{N}(p_j - o_j)^2,$$

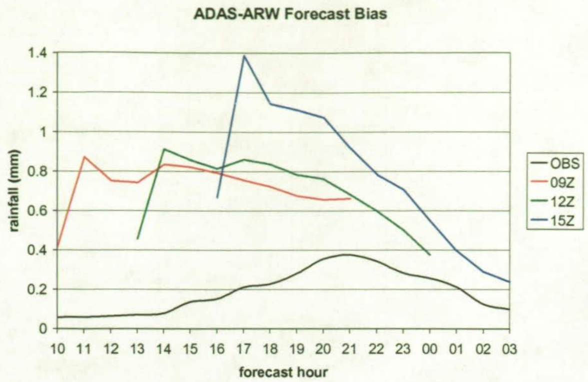
where p_j is the forecast fraction, o_j is the observed rainfall fraction, and N is the total number of grid box fractions.

3. RESULTS

Comparison of hourly model rainfall accumulation to stage-IV rainfall accumulation analyses was made for each forecast for all convection and non-convection days. The stage-IV data was averaged to the same grid as the mesoscale model to give a similar comparison. In addition to assessing the spatial accuracy of the different model configurations, it was important to assess the accuracy of the predicted amounts of rainfall in the verification area, or the forecast bias. It is important to note that the results are limited by the number of candidate days. While a study of the full convective season would be ideal, it was felt that using a handful of representative days would help in obtaining an overall view of the skill of each model configuration.

3.1 *Comparison of WRF Initializations*

Figures 2a, b, and c show the forecast bias for the ADAS-ARW, LAPS-ARW, and LAPS-NMM model configurations, respectively. The black line is the hourly observed rainfall accumulation averaged over the 4-km domain. The red, blue, and green lines represent the averaged forecast rainfall accumulations for all convective and non-convective days for the 0900, 1200, and 1500 UTC runs, respectively. It is apparent that both ADAS-ARW and LAPS-ARW significantly over predict rainfall during the first 5 to 6 hours of each forecast. In addition, both configurations show sharp increases in rainfall accumulation within the first 2 hours of the forecast. During this time, both the ADAS-ARW and LAPS-ARW over predicted rainfall by up to 14 times the observed rainfall, indicating that there is still an issue of model spin up even with a hot-start initialization. The LAPS-NMM configuration also spins up too much rainfall during this time; however, it has a smaller bias than the other two configurations. All ADAS-ARW forecasts consistently over predict rainfall accumulation as well as fail to capture the late afternoon convective maximum. All LAPS-ARW forecasts also over predict accumulated rainfall, however, during the last 6 hours of the 1200 and 1500 UTC runs forecasted precipitation more closely mirrors the observations and the model a)



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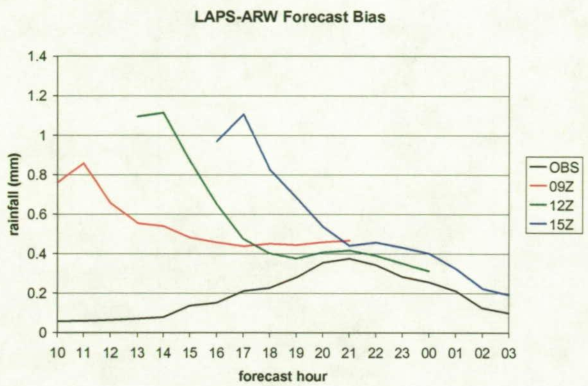

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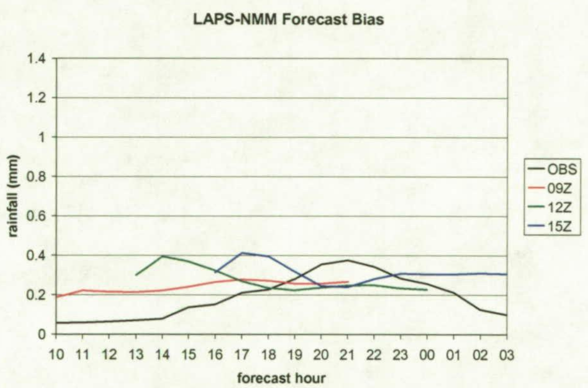
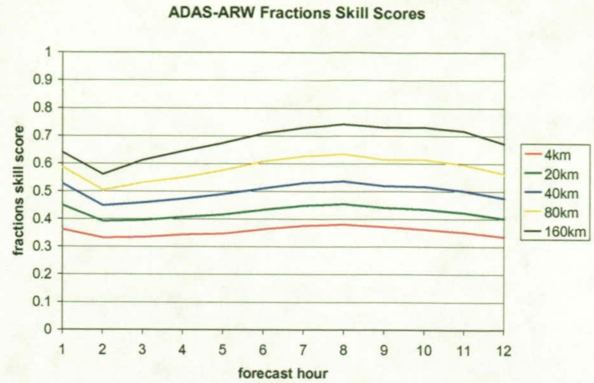


Figure 2. Forecast bias of rainfall accumulation (mm) versus time (UTC) for a) ADAS-ARW, b) LAPS-ARW, and c) LAPS-NMM. The black line is the hourly observed rainfall accumulation averaged over the 4-km domain. The red, green, and blue lines are the averaged forecast rainfall accumulations for all model runs initialized at 0900, 1200, and 1500 UTC, respectively.

a)



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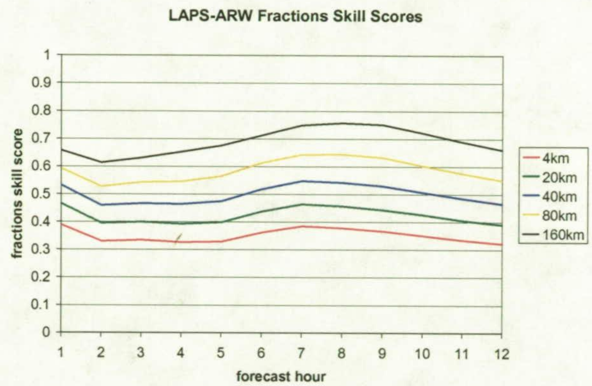

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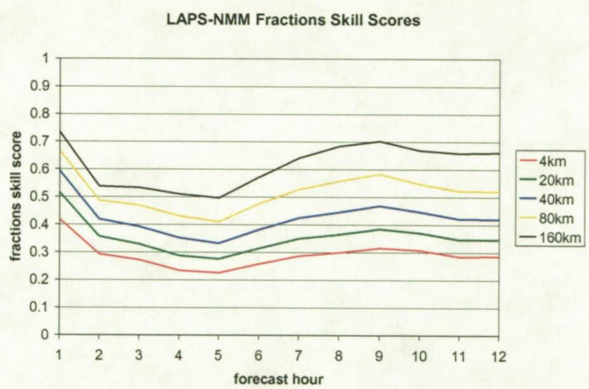

Figure 3. Fractions Skill Score versus forecast hour for a) ADAS-ARW, b) LAPS-ARW, and c) LAPS-NMM. The colored lines represent model skill on different spatial domains, from the grid scale (4-km) to 160-km.

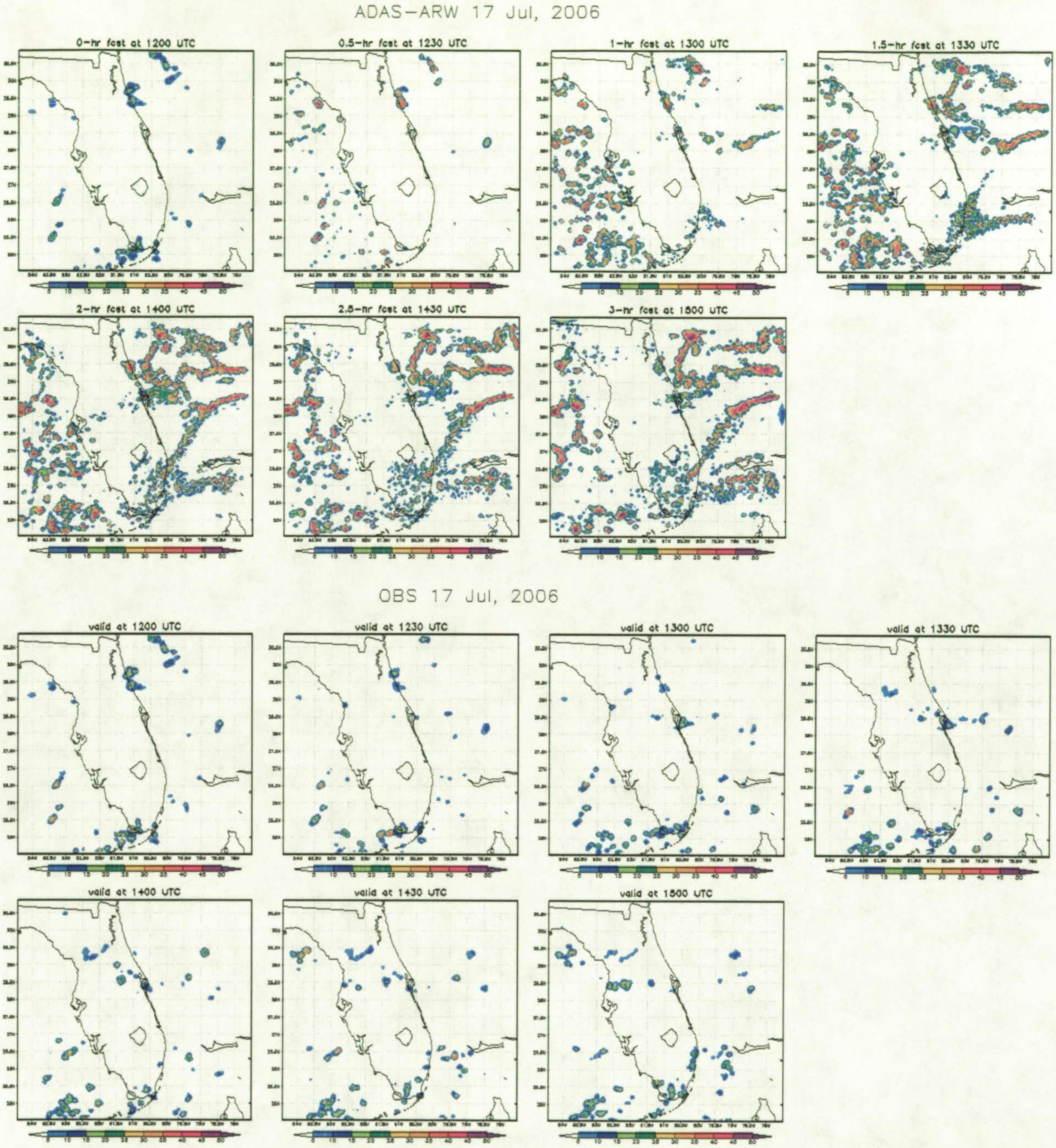

Figure 4. ADAS-ARW forecast composite reflectivity from 17 Jul 2006 initialized at 1200 UTC and observed composite reflectivity valid at the same time.

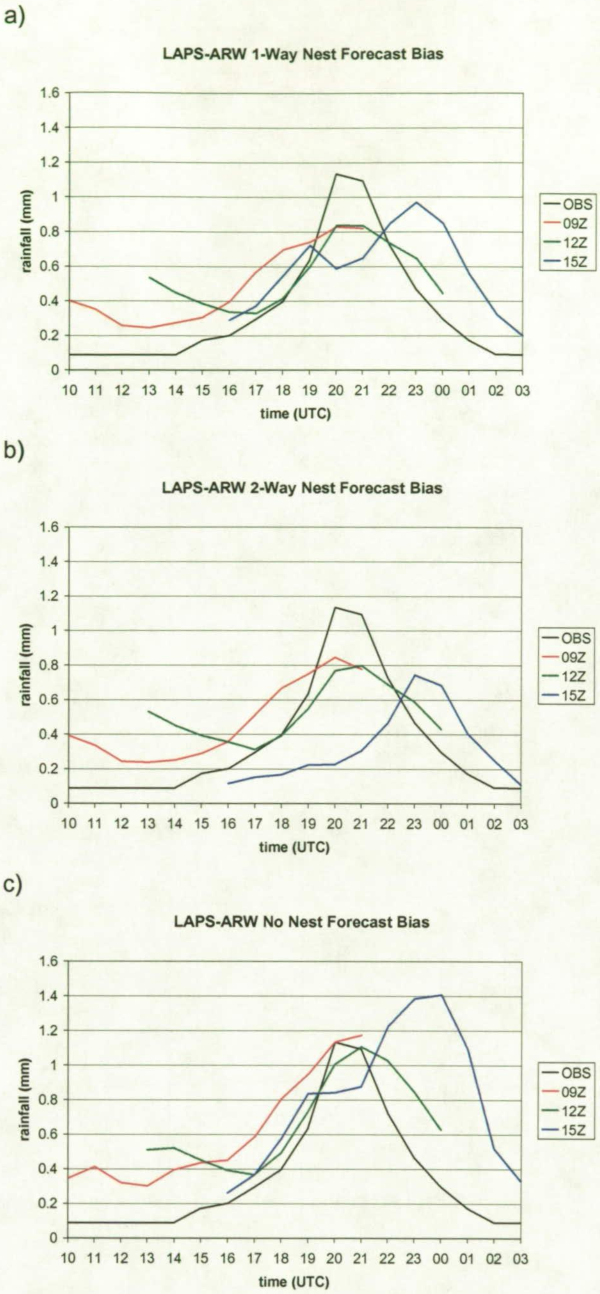

Figure 5. Forecast bias of rainfall accumulation (mm) versus time (UTC) for LAPS-ARW 1.33-km nest using a) 1-way nesting, b) 2-way nesting, and c) no nesting. The black line is the hourly observed rainfall accumulation averaged over the 1.33-km domain. The red, green, and blue lines are the averaged forecast rainfall accumulations for all model runs initialized at 0900, 1200, and 1500 UTC, respectively.

does capture the late afternoon convective maximum. The rainfall bias for the LAPS-NMM configuration is smaller than for both the ADAS-ARW and LAPS-ARW configurations. Nevertheless, not only did LAPS-NMM fail to capture the late afternoon convective maximum, the 1500 UTC run indicated a late afternoon minimum in convective activity.

Figures 3a, b, and c show the results from the calculation of FSS for all three model configurations. This compares fractions from the models to the stage-IV precipitation analysis for five different spatial scales: from 4-km, which is the model grid scale, to 160-km. It is important to note that the score is more sensitive to small rain areas.

Both ADAS-ARW and LAPS-ARW show the least skill two hours after model initialization. This is consistent with the time of the maximum precipitation bias for both model configurations and is due to the model spin up process. To illustrate this, forecast composite reflectivity from the first 3 hours of an ADAS-ARW model run initialized at 1200 UTC 17 Jul 2006 is shown in Figure 4, as well as the observed composite reflectivity valid at the same time. It is evident that not only does the model rain rate exceed the observed rain rate, but the model also predicted too many rain areas over the waters surrounding the Florida peninsula, hence, the low skill and large forecast bias during the initial stages of the forecast. Both model configurations show some skill at predicting warm season convection in the 6 – 12 hour range. LAPS-NMM shows little skill in the 2 – 5 hour range and the least skill overall. For all configurations, model skill in forecasting the distribution of rainfall increased with spatial scale. That is, the skill in forecasting precipitation within 160-km of an area was better than forecasting precipitation within 4-km of the same area. Roberts (2005) notes that the skill should increase with spatial scale until it asymptotes at some value determined by the forecast bias.

3.2 *Comparison of Nesting Options*

Figures 5a, b, and c show the forecast bias for the LAPS-ARW 1.33-km nest using 1-way nesting, 2-way nesting, and no nesting, respectively. The no nesting option is simply a 4-km grid subset over east-central Florida. The black line is the hourly observed rainfall accumulation averaged over the 1.33-km domain. The red, blue, and green lines represent the averaged forecast rainfall accumulations for all convective days for the 0900, 1200, and 1500 UTC runs, respectively. The 0900 and 1200 UTC runs for both the 1-way and 2-way nesting configurations behave in a similar fashion. Both nesting configurations over predict precipitation during the initial stages of the forecast, exhibiting the same model spin up problem as was seen with the 4-km model runs. They do capture the timing of the late afternoon convective maximum, although both under predict the rainfall during this time. The no nesting run also over predicts rainfall over the local domain at the start of both the 0900 and 1200 UTC forecasts, but then accurately captures the timing of the late afternoon convective maximum and the correct amount of rainfall. The timing of the late afternoon convective maximum in the 1500 UTC runs of all nesting configurations was a)

b)

c)

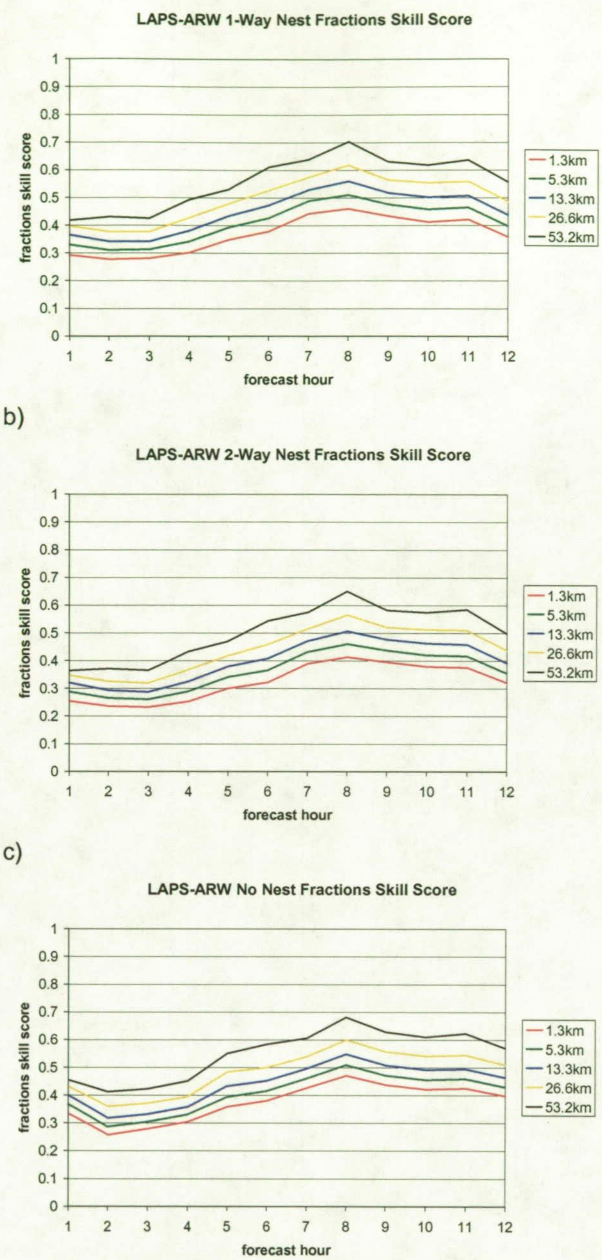

Figure 6. Fractions Skill Score versus forecast hour for LAPS-ARW 1.33km nest using a) 1-way nesting, b) 2-way nesting, and c) no nesting. The colored lines represent model skill on different spatial domains, from the grid scale (1.33-km) to 53.2-km.

delayed by approximately 3 hours. The 1-way nest exhibits two peaks in rainfall, one at 1900 UTC and another one at 2300 UTC. The 2-way nested 1500 UTC run accurately captured the trend in rainfall accumulation, however, it under predicted the amount of precipitation.

a)

b)

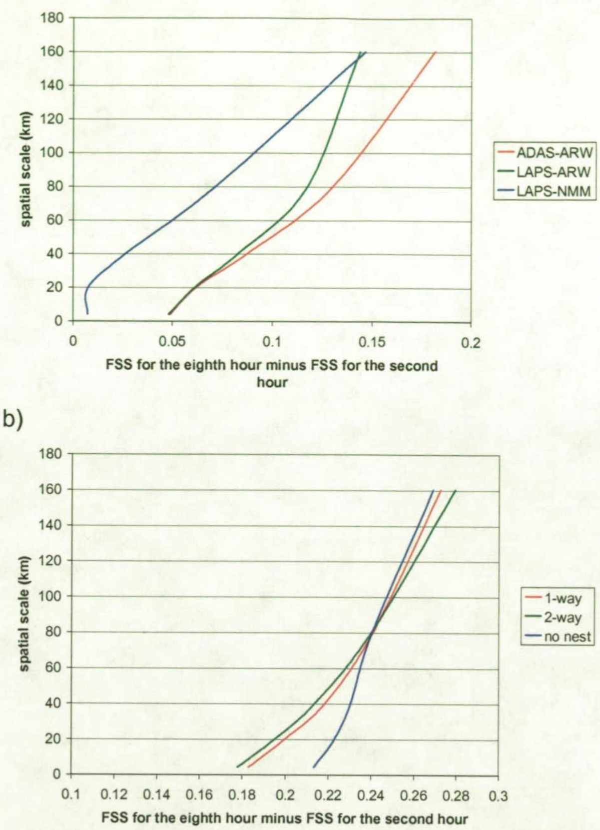

Figure 7. Fractions Skill Score for the eighth hour minus the Fractions Skill Score for the second hour against spatial scale for a) ADAS-ARW, LAPS-ARW, and LAPS-NMM and b) 1-way, 2-way, and no nest model configurations.

Figures 6a, b, and c show the results from the calculation of FSS for all three nesting configurations. This compares fractions from the models to the stage-IV precipitation analysis averaged over the model domain for five different spatial scales: from 1.33-km, which is the model grid scale, to 53.2-km. The FSS of all three nesting configurations look nearly identical. Each configuration increased in forecast skill by nearly 50% from the first six hours of the forecast to the last six hours. This suggests that the model continues to have a problem with the spin up process even when running with a higher resolution on a smaller domain. The FSS for the 2-way nested run was approximately 0.5 less than the FSS for both the 1-way nested and no nest runs. As with the different WRF initializations, the skill of the model in forecasting the distribution of rainfall increased with spatial scale.

5. THE IMPACT OF MODEL SPIN UP

The results from the Fractions Skill Scores for different model initializations (Figure 3) and model nesting options (Figure 6) have shown that the forecast skill increases as the forecast progresses. The size of the impact of model spin up can be seen by measuring the difference in skill between an early forecast hour and a later forecast time. Figure 7a shows the difference in FSS between hour 8 and hour 2 against spatial scale over the verification area for ADAS-ARW, LAPS-ARW, and LAPS-NMM, while Figure 7b shows the same for 1-way, 2-way, and no nesting. These figures illustrate how much model spin up time impacts the skill of the model in the early stages of a forecast, particularly for the 4-km runs over the Florida peninsula. Inclusion of days with active convection at model initiation would amplify the difference in model skill between the early and late forecast hours. The graph reveals that most of the extra skill was added as the spatial scale increased with the exception of the LAPS-NMM model in which more skill was added at the 4-km scale than the 20-km scale.

6. CONCLUSIONS

The evaluation described in this paper is designed to assess the skill of the three different hot-start model configurations of the WRF model and the different nesting options available for forecasting warm season convective initiation. The objective verification of the model configurations focused on the overall accuracy of precipitation forecasts across the Florida peninsula and the surrounding coastal waters, as well as the local east-central Florida region. Results from the evaluation have shown the following.

1) During the model spin up process, too much precipitation develops across the forecast area for both ADAS-ARW and LAPS-ARW.
2) There is a tendency for ADAS-ARW and LAPS-ARW to over predict rainfall amount across Florida and the surrounding coastal waters throughout the forecast.
3) As the forecast progresses, the rainfall bias decreases and the skill increases indicating that all models perform better beyond 6 hours.
4) The difference in skill between the ADAS-ARW and LAPS-ARW is negligible, while the skill of LAPS-NMM is slightly worse than the other two configurations.
5) Both 1-way and 2-way nesting configurations under predict the late afternoon convective maximum over east-central Florida.
6) As with the three hot-start model configurations, the skill of the forecasts for the different nesting configurations increased as the forecast progressed.
7) The difference in skill between the 1-way, 2-way, and no nest configurations was negligible.

The analysis of all hot-start model configurations and nesting configurations indicated that no single model was clearly better than the rest. However, overall LAPS-ARW and ADAS-ARW did outperform LAPS-NMM. It is important to note that the results are limited by the number of candidate days. The information from this study can be used to determine the smallest spatial scales over which model output is presented. If a Fractions Skill Score of 0.5 is deemed acceptable to the user, precipitation output from a LAPS-ARW run represents scales of around 60-km during the first 5-6 hours of the forecast and about 30-km during hours 6-12.

Future work will extend the Fractions Skill Score method to examine the temporal scale as well. A rigorous analysis of the data will be conducted to quantify which model configuration will be the most useful to NWS SMG, NWS MLB, and the 45th WS in their operations.

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14. ABSTRACT
This abstract describes work that done by the Applied Meteorology Unit (AMU) in assessing the success of different model configurations in predicting warm season convection over East-Central Florida. The Weather Research and Forecasting Environmental Modeling System (WRF EMS) software allows users to choose among two dynamical cores – the Advanced Research WRF (ARW) and the Non-hydrostatic Mesoscale Model (NMM). There are also data assimilation analysis packages available for the initialization of the WRF model – the Local Analysis and Prediction System (LAPS) and the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS). Having a series of initialization options and WRF cores, as well as many options within each core, creates challenges for local forecasters, such as determining which configuration options are best to address specific forecast concerns. This project determined that of the three different initialization configurations and three nesting options available, none was clearly better than the rest in predicting warm season convective initiation over East-Central Florida.

15. SUBJECT TERMS
Weather Research and Forecasting Environmental Modeling System (WRF EMS), convection, Local Analysis and Prediction System (LAPS), Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS)

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